# Receiver Architectures with no Intermediate Frequency

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In today's engineering labs, the need to design radio equipment at the lowest possible cost has generated new interest in simple receiver architectures. Some of these concepts are very old, some new, and all can benefit from today's advanced components and design techniques. This short note presents the most common types of receivers that do not require an intermediate frequency (IF), with comments on the advantages and disadvantages of each type.

Receivers that do not require an IF have a few distinct advantages. First, there are no image frequencies and spurious responses are generally limited to harmonics of the operating frequency. They also reduce the amount of RF circuitry and its associated shielding and layout requirements. Most signal processing is accomplished at baseband, where isolation, gain, filtering and control are all more easily accomplished.

The disadvantages of not having an IF are also significant. They include less flexibility in tuning, more difficulty in bandpass filtering and lower sensitivity. High gain in the baseband stages can cause sensitivity to microphonic noise and 50/60 Hz hum. Self-interference is possible in some types which have a local oscillator operating on the received carrier frequency.

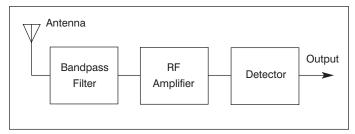
With this background established, let us look at some specific receiver architectures.

### The Tuned-Radio-Frequency (TRF) receiver

The TRF is the second-earliest receiver developed in the dawn of radio technology (an untuned detector being the first). A block diagram of a TRF receiver is shown in Figure 1. All selectivity is provided by a front-end bandpass filter. At low frequency, a high-Q L-C circuit may suffice, while high frequency TRF receivers commonly use SAW filters for front-end selectivity.

An actual receiver can be extremely simple; without the RF amplifier, this is the architecture of early crystal sets. Modern wireless applications occasionally use TRF receivers for short-range links in RF identification (RFID) or remote control applications. To obtain additional gain, filter and amplifier sections can be cascaded, but with the limitation that too much gain at one frequency can cause instability.

A variation on the TRF receiver has been patented by RF Monolithics, called the Amplifier Sequenced Hybrid



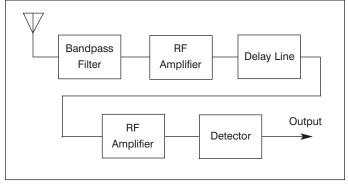
▲ Figure 1. The Tuned Radio Frequency (TRF) receiver is an example of extreme simplicity.

(ASH) receiver (Figure 2). This design addresses the problem of obtaining sufficient gain without risking instability. The delay line eliminates the problem of RF gain by separating the RF amplifiers in *time*, instead of an IF separating them in *frequency*. The overall time constant for a feedback signal that might cause instability corresponds to a low frequency, where the necessary isolation can be readily obtained. The ASH receiver's detector may be simple, putting it in the family of TRF receivers, or it may be super-regenerative, placing it in the next category to be discussed.

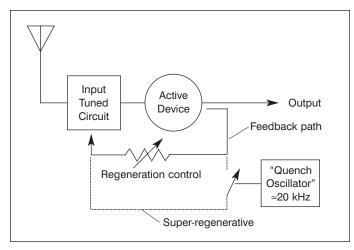
Finally, the ultimate TRF receiver may be one with an analog-to-digital converter as a detector. With a digitized band of signals, analytical software can be used to recover modulation or analyze signal characteristics.

#### Regenerative and super-regenerative receivers

In a simple receiver, *selectivity* is determined by the front-end filter, while *sensitivity* is primarily determined



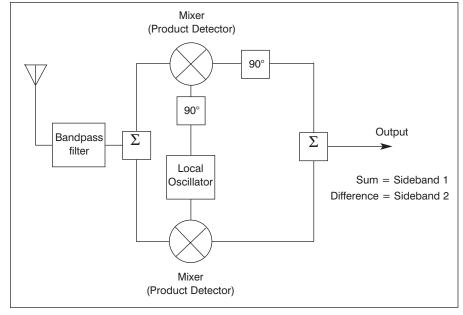
▲ Figure 2. RF Monolithics' ASH receiver uses a delay line to allow increased gain without RF instability.



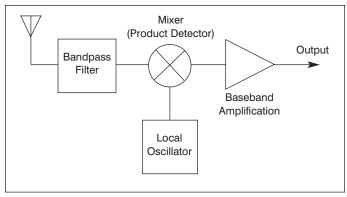
▲ Figure 3. Regenerative and super-regenerative receiver block diagram.

by the detector. Only a limited amount of RF gain is practical prior to the detector compared to a receiver with an IF, where 100 dB (or more) gain may be available ahead of the detector. Most simple detectors have significant loss, adding to the problem of obtaining sufficient sensitivity to be useful. Figure 3 shows the block diagram of the two types of detector described next.

Around 1915, the regenerative detector was developed. This type detector is based on the behavior of an oscillator at the critical operating point where oscillation is just barely sustained. At waveform peaks, the gain of signals through this circuit reaches an unusually high value, as feedback creates a high Q in the input tuned circuit. Regenerative receivers include a manual "regeneration control" that adjusts the feedback, so that the detector's oscillation threshold can be maintained



▲ Figure 5. Phase-shift method SSB direct-conversion receiver.



▲ Figure 4. The homodyne, or double-sideband direct-conversion receiver.

with changing frequency and with the influence of strong input signals.

Because manual adjustment is required, regenerative receivers are impractical for mass-produced wireless communications. This shortcoming was addressed by the super-regenerative detector's invention. The term "super" was not coined for marketing purposes, but because a super-audible (20 kHz or higher) signal was the key to its operation. In a super-regenerative detector, the manual regeneration control is replaced by this inaudible "quench oscillator" signal (dotted line in Figure 3), which cycles the detector through its critical gain point at an inaudible rate. The result is a detector with nearly the sensitivity of the original regenerative type, but with no manual adjustment.

Super-regenerative detectors are common in wireless remote control devices. These receivers use an architecture like that shown on Figure 1, using a super-regenerative detector. They typically have a SAW filter for front-

end selectivity, although some older designs may still have L-C filters. Within the FCC limits for radiated power from the transmitter, a superregenerative remote control receiver can provide 100 to 300 feet of range.

#### **Direct-conversion receivers**

At about the same time as the regenerative detector was developed, the homodyne detector (Figure 4) was also invented. This detector is essentially an input filter followed by a product detector, a mixer that translates the carrier frequency to baseband, where it is amplified. It was not until the 1970s that this "direct-conversion" technique became popular as a receiver, although its fixed-tuned version (the product detector) had been widely used for many years.

# DESIGN IDEAS

Most early radio signals were AM modulated, and this type detector created an audible beat note unless it was exactly synchronized with the carrier frequency of the received signal. Although this type detector works well with continuous wave (CW) transmission used for Morse Code, the high performance of a superheterodyne receiver made simpler receivers unnecessary.

In the early 1950s, single-side-band (SSB) techniques were thoroughly developed as a spectrum-conserving, power-efficient means of voice transmission, initially for military communications. One of the methods developed for SSB involved the use of two 90-degree phase shifts to mathematically cancel one of the two sidebands that would be created by a simple product detector (or

homodyne receiver). As shown in Figure 5, this method requires two detectors and supporting phase shift circuitry in a relatively complex system. However, the extent of the RF circuitry is much less than a superheterodyne circuit, and a number of recent developments in analog and digital IC technology have made this type of receiver more practical than it was a few years ago.

The 90-degree RF phase shift required for the two local oscillators can be obtained with divide-by-four digital circuits or with two PLLs locked in quadrature. Analog baseband phase shift networks can provide adequate performance, but implementation of a Hilbert Transform (broadband 90-degree phase shift) in a digital signal processing (DSP) IC can provide a high degree of phase accuracy, and allows computer-controlled compensation for phasing errors.

By now, you may have noted that the output of the two detectors are baseband I (in-phase) and Q (quadrature) representations of the received signal. With the proper signal processing, any modulation format can be accurately recovered from this quadrature data.

This method is already used in some paging receivers for detecting and demodulating BPSK data signals. Bi-phase demodulation does not require highly accurate phase shift performance. While 20 dB overall rejection of the unwanted sideband will result in poor performance in voice communications, it is good enough for reliable discrimination of one phase state from another. This performance corresponds to about a 3-degree error in both the RF and baseband phasing, which is easily obtained with simple passive phase shift networks.

## Summary

Hopefully, these notes on "no IF" receivers will be useful in the investigation of the lowest cost solution to your wireless communications system design assignment.